AN ENERGY ALLOCATION MODEL

Dr. Subhash Datta
Director, Centre for Inclusive Growth and Sustainable Development
M-134 South City I, Gurgaon 122007, India
subhash.datta@gmail.com

ABSTRACT

The paper estimates the present and future energy demands of a rural area. It considers the available sources of energy and discusses their prospects of satisfying future demands. A linear programming (allocation) model is formulated to meet the demands at the minimum cost. The model emphasizes the use of local and renewable sources of energy. The results of the model show that with the present plans the local sources of energy would not be able to sustain the envisaged area development strategy. For any self-sufficient development, the local sources of energy would have to be greatly increased for satisfying future demands.

Keywords: Energy Demand and Supply; Allocation Model.

AN ENERGY ALLOCATION MODEL

I. INTRODUCTION

In India more than 60% of the population lives in rural areas, of which approximately 30% are below the poverty line. The past development strategies have benefited the well to do farmers and hence accentuated the income inequalities of rural areas. Any alternative strategy of area development must result in:

- A more equitable distribution of income
- More employment opportunities for the weaker sections
- Full utilization of local resources, particularly land and water
- Increase in farm productivity to meet the basic needs

To achieve these objectives, the rural development strategy must include;

- Better management of land and water (increased irrigation and planting of trees on waste lands)
- Improved agricultural practices (multiple cropping pattern and inter- cropping)
- Introduction of simple production methods so as to reduce the demand for skills
- Development of energy saving technologies based on renewable and low cost materials.

Such a development strategy would result in an increased demand for energy. The increased demand should mostly be met by local and renewable sources for the following reasons:

- The use of local resources enables full utilization of resources which would otherwise be wasted.
- The supply of external fuels can be difficult due to poor transportation and low levels of national supply.
- Conventional energy sources can be used in other sectors (say in heavy industry)
- The use of renewable sources is preferable to sources of energy which are limited.

However, before one can select an appropriate energy strategy for rural areas one must take audit of the present position regarding energy use and energy needs to fulfill developmental objectives outlined earlier. The present paper is designed to examine these questions. Thus the paper investigates the energy use in a representative block “BAISHALI” to find out whether local sources of energy would be able to sustain the kind of rural development envisaged. The paper is presented in 5 sections. Section II investigates the energy demands of Baishali block and discusses the possible levels of development and corresponding energy demands. Various energy sources are investigated in Section III. The availability and potential for satisfying the demands are also considered. An allocation (LP) model is formulated in Section IV so as to satisfy the energy demands from the available energy sources in the best possible way. The model is applied to the data generated for the hypothetical block Baishali and the results are presented in Section V.

The energy demand and source linkages are shown in Figure 1 and the various components of the study are presented in the flow chart in Figure 2.

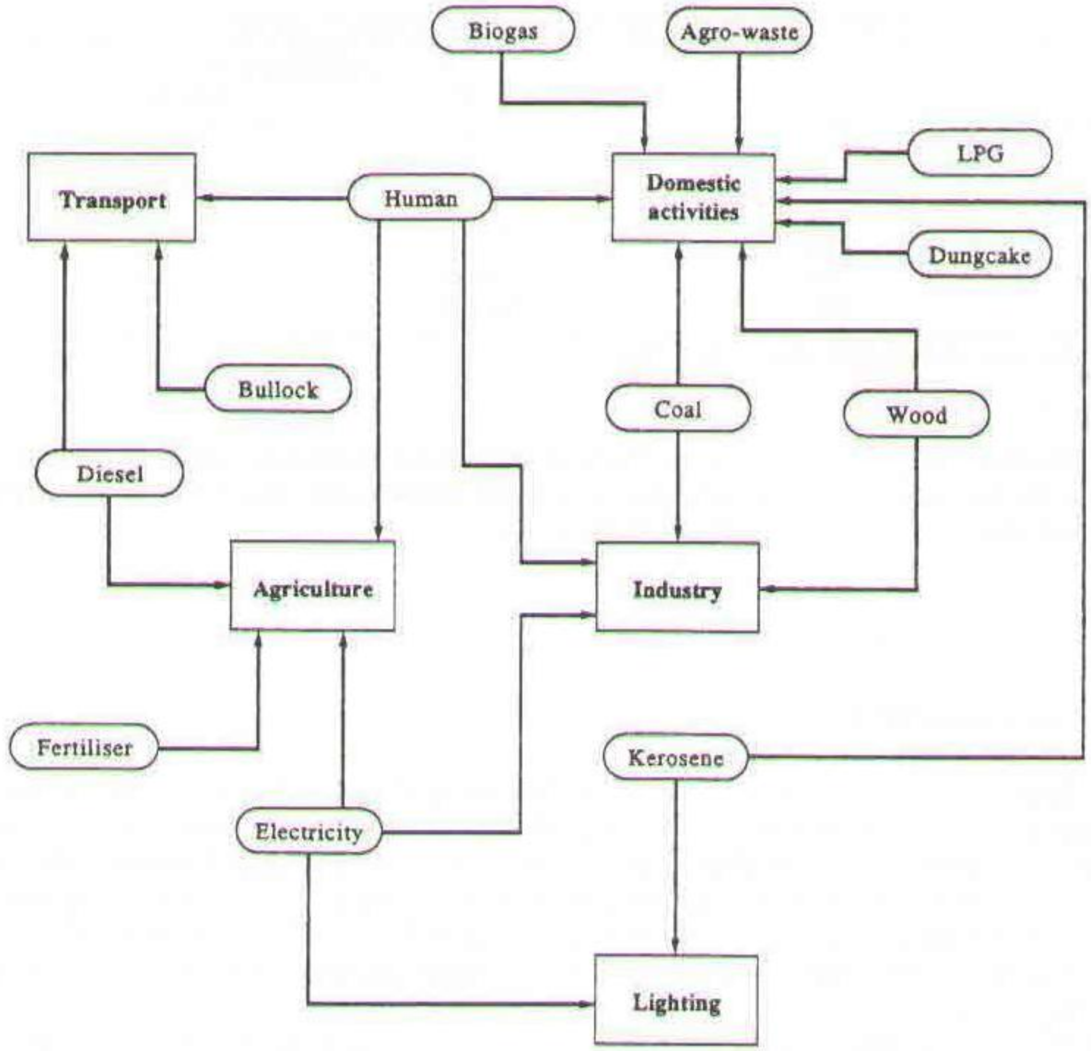

Fig. 1. Energy demand–source linkages.

II. ENERGY DEMANDS

To estimate the future demands for energy it is necessary to determine first the current pattern of energy use. Energy is required to meet basic human needs. The principal energy needs are:

- agricultural fuels (for irrigation, fertilizers, crop processing, food transport and storage)
- cooking and lighting
- domestic water supply(including the requirement of hot water)
- transportation
- other services

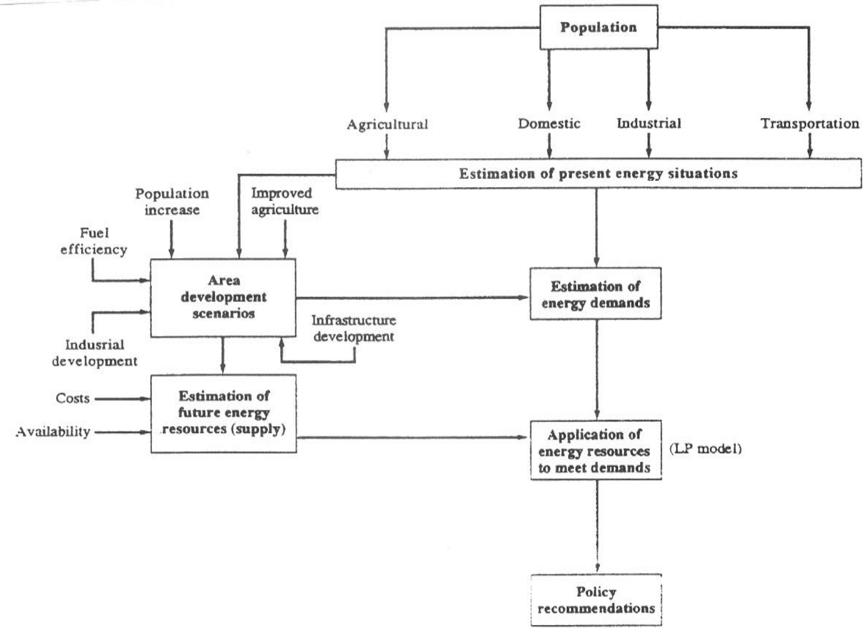

Fig. 2. Energy Management System.

We consider the energy demands of Baishali block in three broad groups;

(a) Domestic demands
(b) Agricultural demands
(c) Industrial demands

The block 'Baishali' has a population of 100,000 (2011 Census), 150 inhabited villages and covers an area of 80,000 hectares. Within the framework of the study a comprehensive survey of energy use was not attempted. Another problem in data collection is the distinction between 'commercial' and 'non-commercial' forms of energy. It is assumed that non- commercial fuels satisfy more than 70% of the energy needs in rural areas. However, many studies fail to account for these sources. A further distinction to be made is the difference between energy input and 'useful' energy input. The useful energy is the energy that is required to perform work given 100% efficiency whereas the energy input is the amount of energy actually used when performing the task with a specific energy source. The two are linked by a factor giving efficiencies of different fuels to perform the job[a].

i.e. $U_j = e_{ij} E_{ij}$

where U_j= useful energy required for job j (energy units)

e_{ij} = efficiency of fuel i to perform job j

E_{ij} = energy input needed from fuel i to perform job j(energy units)

(a) Domestic demands

The two important basic forms of domestic demands are cooking and lighting. It is estimated that 97% of domestic energy use is for cooking only. Many such studies show that the average value of energy requirements in rural areas is approximately $2 * 10^6$ Kcals/capita/year. We take the above figure as an estimate of domestic energy use in Baishali block. The dominant form of energy source is firewood and agro – waste (approximately 90% of domestic energy sources).

The useful energy obtained from these sources are very low considering the relatively low efficiency the relatively low efficiency of firewood and agro-waste. The Khadi and village Industries Commission (KVIC) gives the following values for the efficiencies of various cooking fuels (Table 1).

For example, boiling water needs certain amount of energy, which can be supplied by, say, electricity and firewood. However, efficiency of fuel wood is only 17% whereas that of an electric stove is 70%. Efficiency is also dependent on the conversion technology.

Energy Source	Cooking Efficiency (%)
Firewood/ Agrowaste	17
Cowdung (dry)	11
Electricity	70
Kerosene/ coal & coke	20
Biogas	60

Table 1: Cooking Efficiencies of various Energy Sources (KVIC)

Using the above efficiency factors to the estimates gives an useful energy demand for domestic activities as $3.6 * 10^5$ Kcal / capita/ year. Multiplying this with the population of 'Baishali' gives the total useful energy demand (domestic) as $3.6 * 10^9$ Kcal / year.

The future domestic demand should also consider

i) The forecasted population growth
ii) Possible technological changes
iii) Changes of lifestyle due to development of the area as well as external influences.

(b) Agricultural Demands

To estimate the present agricultural energy demands we must find out the present agricultural practices of 'Baishali'. The present land use pattern shows that 50% of the geographical area is cultivated of which 40% is irrigated (20% of total geographical area). Only 2% of the area cultivated is double cropped. The land under forest is 25% and uncultivated barren land including fallow land is 21% of the total area. The predominant Kharif crop is paddy (20000 hectares) whilst in the Rabi season Jowar is mainly grown (21,310 hectares) and other crops are oil seeds (3230 hectraes), pulses (3177 hectares) and others (3028 hectares).

Traditional methods are practiced with minimal reliance on commercial source of energy. The crop yields in the district are poor. 37% of the net area sown is irrigated, most of the irrigation water being used for paddy (93.28%). Cowdung is mostly used as fertilizer and chemical fertilisers are only used in irrigated land. The average annual consumption of chemical fertilizer per hectare of irrigated land in Baishali is 28.2 kg. of mixture and 9.8 kg of Nitrogen, whereas the requirement would be about 100 kg/hectare. The estimate average consumption of organic manures is approximately 500 kg/hectare.

The agricultural demands of energy will, however, depend on other factors such as soil condition, water resources, local climate and previous use of the land. We have made a rough estimate of demand on the basis of average number of bullock pair days per hectare of crop grown. The useful energy factor gives an energy efficiency of 18.7%. The actual energy is 644,000 Kcal/ hectare and useful energy is 120,440 Kcal/hectare. Considering 55,485 hectares of gross cropped area we get the useful energy demand for agriculture to be $6.65 * 10^9$ Kcal/year (i.e. 14% of total domestic demand). To estimate energy demand for irrigation we compared various estimates and accepted that energy required per hectare irrigated to be $6 * 10^5$ Kcal/hectare. The estimate seems to be reasonable. The total energy requirement for irrigation block is then $1.2 * 10^{10}$ Kcal. Assuming 20% efficiency of pumps gives an useful energy demand of $2.4 * 10^9$ Kcal.

Future demand

Future agricultural development needs a well dispersed increase in yield rather than in a few pockets of land.

The following encouragements should be given

(a) Efficient use of local water resources
(b) Use of local renewable energy sources
(c) Recycling of agricultural wastes
(d) Replacement of chemical fertilizers by bio- fertilizers
(e) Overall improvement of agricultural practices

For efficient use of water resources we have to develop a well-managed irrigation system. Besides the need for pumping water energy is also required for preparation of land, construction of dams, tanks, wells and construction of the conveyance system.

Further, availability of materials and machines should also be accounted for the above constructions.

There are a number of other problems involved in the process of agricultural development. Some of them are

(i) The education of the villagers
(ii) The supporting administrative infrastructure and a better communication network
(iii) The structure of land holdings

Future agricultural energy demand must consider all the above factors as well as the following:

(a) The projected gross cropped area, multiple cropped area and irrigated area
(b) The development of improved agricultural practices
(c) The future demand of chemical / bio fertilisers.

(c) Industrial Demands

This demand is negligible compared to domestic and agricultural energy demand ranging from 4% to 6% in rural areas.

No major industrial complex is planned in the near future in the block. The industrial energy demand will remain a small proportion compared to domestic/ agricultural demands over the next decade.

The following Table gives the details of energy demand scenarios of “ Baishali ‘ block

Table 2 : Demand Scenarios (2011)

Factor considered	Pessimistic	Most Likely	Optimistic
1. Popluation	1,00,000	1,00,000	1,00,000
2. Cooking demand per capita (Kcals)	$3.5 * 10^5$	$3.5 * 10^5$	$3.85 * 10^5$
3. Total Cooking demand (Kcals)	$5 * 10^{10}$	$5 * 10^{10}$	$5.5 * 10^{10}$
4. Lighting demand per capita (Kcal)	$0.1 * 10^5$	$0.15 * 10^5$	$0.2 * 10^5$
5. Total Lighting demand (Kcal)	$0.14 * 10^{10}$	$0.21 * 10^{10}$	$0.28 * 10^{10}$
6. Irrigated Area (hectares)	20,347	23,806	26,044
7. Total irrigated demands hectares(g)	$2.4 * 10^9$	$2.86 * 10^9$	$3.1 * 10^9$
8. Gross Cropped Area (hectares)	55,485	56,040	59,370
9. Total agricultural demand (Kcals)	$6.65 * 10^9$	$6.72 * 10^9$	$7.12 * 10^9$
10. Organic fertliser per hectare(kg) (K)	500	550	600
11. Total fertilizer demands (Kcal)	$2.7 * 10^7$	$3.1 * 10^7$	$3.6 * 10^7$

III. ENERGY SOURCES

The development of local energy sources is an important aspect of rural development. The criteria for local energy sources are that:

(i) The technologies involved must be simple and acceptable by the simple minded villagers
(ii) They should utilize accessible materials
(iii) They should preferably be labour intensive
(iv) They should need minimum maintenance

The various energy sources considered are:

(a) Human power
(b) Animal power
(c) Forest wood
(d) Bio-gas
(e) Rural electrification
(f) Solar energy
(g) Wind energy

The supply of energy from commercial sources such as gas, oil and nuclear fuels are not considered. The availability and development of these sources is decided on a national level and as such, outside the scope of the study.

The availability scenario considered the number of biogas plants constructed, the area of fuel wood plantations and the number of animals in the area.

Considering different rates of development we have generated three development scenarios (optimistic, pessimistic and most likely). The scenarios were based on the assumption regarding the future state and national levels plans for the next 5 years.

Table 3 gives the details of the availability scenario of energy sources in Baishali block.

Table 3: Availability Scenarios (2011)

Factor considered	Pessimistic	Most Likely	Optimistic
1. No. of biogas plants	57	172	256
2. Biogas availability (ft^3)	$4.4 * 10^6$	$13.2 * 10^6$	$19.6 *10^6$
3. Area of fuel wood plantations (hectare)	0	106	228
4. Fuel wood availability (kg)	0	$5.3 * 10^6$	$9.4 * 10^6$
5. No. of Buffaloes Cattle Young	7370 43470 16452	7790 45948 17390	8033 47382 17933
6. Cowdung availability (kg)	$1.7 * 10^8$	$1.8*10^8$	$1.9 *10^8$
7. No. of working males	29195	30860	31822
8. Animal power availability (hrs)	$4.9 * 10^7$	$5.1 *10^7$	$5.3 * 10^7$

IV. AN ENERGY ALLOCATION MODEL

Firstly, the system generates energy demand scenarios at the block level under different socio-economic and environmental conditions. The energy demand was divided into four major components (Domestic, Agriculture, Industry and Transport). The energy demand – source linkages can be seen in Fig. 1. An allocation model was then developed which uses Linear Programming for the optimum allocation of the energy resources at the block level. The methodology is given in Figure 2. The supply of energy sources is to be provided by the user to obtain the optimum allocation. The model can be represented as follows:

$$\text{Minimise } X_0 = \alpha \sum_{j,i \in E} C_i X_{ij} + \sum_{j,i \in I} C_i X_{ij} \text{ (Objective function)}$$

$$\text{Subject to } \sum_j K_i e_{ij} X_{ij} \geqslant D_j \text{ (Demand)}$$

$$\sum_i X_{ij} \leqslant A_i \text{ (Availability)}$$

$$X_{ij} \geqslant 0 \text{ (Non-negativity)}$$

Where

Xij =Amount of energy from source I to demand j

Ci = Cost per unit of source i

Ki =Conversion factor of unit of source I into kcals

eij = Efficiency of using source I for demand j

Dj = Useful energy for demand j in kcals

Ai =Availability of source I in kcals

α = External weighing factor

i ϵ E= Set of external energy sources

i ϵ I = Set of internal (local) energy sources.

There are 33 variables and 27 constraints in the model.

The Energy Management System (EMS) can be effectively utilized for optimum allocation of the energy resources among competing demands. However, this interactive program allows the user to vary the resources available as well as demand so as to generate many alternative resource use profiles. This exercise of generating alternatives helps the decision makers to understand the worth of each unit of the resources and indirectly offers some flexibility in the decision making process.

For testing the model, data were collected from a block of Bankura district in West Bengal state. The results are encouraging in the sense that the relative importance of the energy resources can be observed from the output of the model. It is hoped in the near future that the forthcoming introduction of a new Science and Technology Department at the district level will enhance the utility of such a comprehensive energy management package for the effectiveness of local area management and planning.

V. APPLICATION OF THE MODEL TO BAISHALI

A simplified version of the model is applied to the data from the block. The flow chart, (Fig.2) represents the situation modeled. In the model, there is no explicit cost constraint. The costs were obtained from enquires in the block and estimates from local official sources. The various fuel costs are listed below:

Source	Cost
Electricity	Rs. 6 / Kwh
Kerosene	Rs. 5/ litre
Diesel	Rs. 35/ litre
Biogas	Rs. 8 / ft^3
Fuelwood	Rs. 40/kg
Cow dung	Rs. 50/kg

The three demands and availability scenarios were considered according to the different rates of development as given in Table 2 and 3.

Results:

The programme was run three times using the (pessimistic) demand and availability figures, with

α = 1,5,10. Several combinations of the different development scenarios were investigated. These included:

(1) Maximum Demand and Maximum Availability Scenario:

Corresponding to the maximum demand envisaged and the maximum available local sources of energy with $\alpha = 1$, electricity is still used extensively, with cow dung for fertilizer and animal power for agriculture. However, with $\alpha = 10$, biogas, fuel woods and cow dung are utilized. This reduces the electricity demand by 32%.

(2) Maximum Demand and Minimum Availability Scenario:

This corresponds to maximum demand with minimum local fuel availability. Even with maximum utilization of these fuels, electricity satisfied 87% of cooking demand.

(3) Minimum Demand and Maximum Availability Scenario:

With minimum demand and maximum availability, the local sources cannot sustain a self – sufficient form of development. Electricity satisfied 62% of domestic demands.

The solutions of the LP models clearly show that with the current state of technology, the local available sources of energy will not be sufficient to sustain the form of area development envisaged. The local sources of energy would have to be greatly increased (though energy plantation/ production of bio mass) for any self- sufficient development of rural areas. The results are, however, based on a static LP model. For realistic planning the model will have to be extended to a dynamic model. Sensitivity analysis will have to be carried out to understand the inter relationships of the variables and also to incorporate realistic estimates of the parameters (based on a comprehensive survey of energy use in the block which is currently under process).

References